POTENTIAL FOR GROUND WATER CONTAMINATION

FROM

PETROLEUM AND URANIUM EXPLORATION AND DEVELOPMENT ACTIVITIES: ASSESSMENT AND RECOMMENDATIONS

DRAFT FINAL REPORT

Please review and send any comments to the YTAPO, Box 503, Broadus, MT 59317

YELLOWSTONE-TONGUE APO
BROADUS, MONTANA

PROJECT NUMBER 6023

JULY, 1977

PARTIAL COPY

Only those parts of this report believed to be of general interest have been included.

This report was financed by a Section 208 Areawide Waste Treatment Management Planning Grant from the U.S. EPA.

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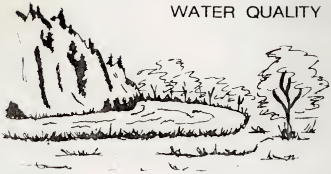

WATER QUALITY MANAGEMENT PROJECT

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CLARK JUDY, Director | DOREL A. HUNT, Planner | AMBREY GARTNER, E I T

July - 1977

TO: Those reading this report.

FROM: Clark Judy C.J.

This is a partial copy of Willard Owens Associates report on groundwater. The entire Table of Contents has been reproduced. Those parts of the report that are missing from this copy include the descriptions of geology and water quality and several fold out illustrations.

I assumed that none of this material would be controversial and that the cost of reproducing 60 copies of it for preliminary review was not justifiable.

A complete copy of the draft report is available in our office.

Copies of the entire final report will be available upon request.

CJ/dt

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July 26, 1977

Mr. Clark Judy, Director
Yellowstone-Tongue APO
Post Office Box 503
Broadus, Montana 59317

Re: Yellowstone-Tongue APO
Project Number 6023

Dear Clark:

In accordance with our Ground Water Quality Assessment contract with your organization, we transmit herein two copies of our draft report entitled "Potential for Ground Water Contamination from Petroleum and Uranium Exploration and Development Activities: Assessment and Recommendations".

Some of our findings will possibly be updated or revised after we obtain and review the ground water quality supplement from the Montana College of Mineral Sciences and Technology compilation; the July, 1977 report on enhanced oil recovery from the Office of Technology Assessment (U.S. Government), and additional material dealing with the chemistry of injection fluids, all of which it was not possible to review for this draft.

We hope this report will be satisfactory for your purpose at this stage. If you have any questions concerning this or any other aspect of our study, please do not hesitate to call on us.

Sincerely,

R. G. Shepherd

Russell G. Shepherd, Ph.D.

Willard G. Owens

Willard G. Owens, P.E.
Certified Professional Geologist

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SECTION I

INTRODUCTION

I. INTRODUCTION

PERSPECTIVE

In 1972 Congress passed, and the President signed into law, the Water Pollution Control Act Amendment. Section 208 of this law concerns "area-wide waste treatment management". Regional planning groups were authorized under Section 208 to provide comprehensive approaches to water quality improvement. The overall objectives of the law are to maintain good water quality, upgrade quality where necessary, and most importantly, plan to prevent future water quality problems to the best interest of individual streams, river basins, and the total environment.

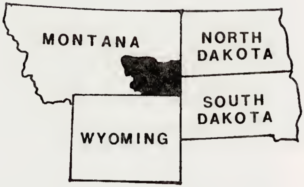
A recent survey made by the National Water Well Association, including 150 Section 208 planning groups, discovered that nearly 80% of the "208" groups did not take adequate action with regard to ground water pollution related to waste disposal in their areas.

Fortunately, the Yellowstone Tongue planning group initially recognized the significance of potential ground water contamination in their Southeast Montana area. Because the exploration for oil, gas, and uranium are of significant importance in the area, efforts were undertaken to establish related potential for ground water contamination. In this regard, Willard Owens Associates, Inc., consulting engineers and ground water hydrologists, were engaged to provide an investigation of potential water quality problems related to the extraction of and

exploration for petroleum and uranium. The study was established to include exploratory drilling programs related to uranium, tertiary oil recovery processes, seismic exploration drilling, solution mining for uranium, and other related activities. This report is the product of that investigation.

LOCATION AND EXTENT OF AREA

The Yellowstone Tongue project area includes Carter, Custer, Fallon, Powder River, Rosebud, and Treasure counties and the northern Cheyenne reservation in southeastern Montana (Figure I-1).



GROUND WATER OCCURRENCE AND SIGNIFICANCE

The climate of southeast Montana is semi-arid. As is common in semi-arid regions, ground water is an extremely important natural resource and is widely used for domestic, stock, municipal, industrial, and irrigation purposes. In addition, the secondary recovery of petroleum and strip-mining of coal consume significant quantities of ground water.

Data compiled recently by the Montana College of Mineral Science and Technology show that there are approximately 6,000 wells in the Yellowstone Tongue project area averaging approximately 225 feet in depth. These data emphasize the shallow nature of most wells. Wells more than 300 feet are uncommon, although in east central Montana, some wells for domestic or stock purposes exceed 1,200 feet in depth.

Alluvial deposits of sand and gravel that occur along stream valleys are common sources of shallow ground water in the area. In addition, sandstone beds in the Arikaree formation, White River group, and the Wasatch formation yield locally-important but usually small quantities of water. The Fort Union formation occurs at the surface over 50% of the project area and contains sand beds and numerous, economically-significant beds of coal that may provide water of good chemical quality. The Hell Creek and Fox Hills formations underlie most of the area and are usually sought to

obtain greater amounts or softer water than that available from the shallower formations. Although older geologic formations, such as the Judith River, locally provide ground water, the potentially most significant deep aquifer is the Madison Limestone, which underlies the entire area at great depths (for example, the top of the Madison is about 4,000 feet below sea level, or about 7,000 feet below ground level, at Broadus, Montana). The Madison contains large quantities of water of commonly-good but highly-variable quality that is artesian (at Broadus, the potentiometric surface, which is the level that water would rise in a tightly-cased well, is about 500 feet above the land surface).

PETROLEUM AND URANIUM OCCURRENCE AND SIGNIFICANCE

Twenty-two oil fields have been discovered in the Yellowstone Tongue project area (Table I-1). One new field, the Breed Creek, was discovered in September of 1976 in Rosebud county. In 1975, production from the six counties of the project area constituted 59% of the total Montana production, and reserves for the same area are 54% of the total Montana reserves. Thus, oil production from the Yellowstone Tongue project area is of great significance, considering that from all of Montana.

Of 248 wildcat wells drilled in Montana in 1976, only 29 were in the Yellowstone-Tongue project area, and only one of these was successful. Essentially the same percentage (11%) of the 538 development wells drilled in the state in 1976 were in the Yellowstone-Tongue area. These data indicate that the major emphasis on Montana exploration has shifted away from the project area, although some continued efforts are expectable.

Oil fields in the area occur as clusters in northwest Rosebud county, southeast Powder River county, and Fallon county (Figure I-2). The Bell Creek field dominates the group in Powder River county, and is the largest in the area. It is 15 miles long, 3.5 miles wide, and has 305 active producing and injection wells associated with six secondary recovery units. Bell Creek

production averaged approximately 24,000 barrels of oil per day in 1976. An enhanced recovery project, funded in part by ERDA, is in the early stages of testing at the Bell Creek field.

Historically, Colorado, Wyoming, New Mexico, Utah, Texas, and Nevada have been major targets for uraniun exploration. Lesser emphasis in the past has been extended into evaluating uranium resources in Montana, North Dakota, and South Dakota. Due to the shortage of uranium (Figures I-3 and I-4), areas of past minor emphasis are becoming targets for more active uranium exploration.

During the course of our work, we reviewed numerous publications discussing uranium occurrence in southeastern Montana and contacted mining companies who have explored in the area to evaluate the potential uranium development in southeastern Montana. The results of our work indicate that presently the largest amount of interest is in the Fall River, Lance, and Dakota formations in the area around Alzada. Apparently Kerr-McGee, Mobil, and possibly Exxon have located deposits of sufficient grade that may show potential for mining.

A secondary area of importance is the Tertiary age sediments of the Fort Union and the Cretaceous age sediments of the Hell Creek and Fox Hills formations of the Powder River Basin. Widely spaced exploration has

occurred intermittently in these formations with no reported significant discoveries. Due to the similarity of the geology between the northern Powder River Basin of southeast Montana and that of the southern Powder River Basin will be further explored for uranium in the future.

Another area of interest is the lignitic coal deposits that are uranium bearing in Carter county, Montana. Several companies have studied the feasibility of removing uranium from the coal, although to date no practical method has been found to economically separate the two energy sources. The uranium normally occurs in an average concentrate of less than .01 percent uranium. Consequently, a large volume of coal must be mined and treated in order to remove the uranium. At this time, mining the uranium requires destroying the coal. If either the coal or the uranium could be a useable by-product of the other extraction, then mining of the uranium may be economical.

PURPOSE AND SCOPE

Activities related to the exploration for and development of uranium and petroleum involve the potential for polluting ground water supplies. Exploratory drill holes, of necessity, commonly penetrate those aquifers which provide water for private as well as municipal and agricultural purposes. Several methods of contamination of these aquifers are possible. If aquifer contamination does occur, health hazards may be created that may require years to alleviate or may never be rectified.

This investigation was established in order to examine problems associated with potential aquifer contamination in the project area and to develop recommendations for the prevention of future contamination. The study was set up to include but not be limited to the investigation of potential water quality problems related to well casing leaks, radioactive tracers, tertiary and secondary oil recovery techniques, pumping or flowing of saline water, seismic exploratory techniques, solution mining, and cross-contamination as the result of natural geologic factors which have been altered by man.

As the investigation developed, certain limitations were encountered. A paucity of necessary data existed. For example, no comprehensive summary or compilation of ground water in the project area was available. To alleviate this problem, the Yellowstone-Tongue APO engaged the Montana College of Mineral Science and Technology to compile a

comprehensive summary of ground water data, including water quality, for the entire area. Their first publication includes geologic maps, topographic maps, and maps showing well appropriation, depths and water levels, sodium adsorption ratios, and total dissolved solids. Supplement B of their study, which will provide water quality analysis showing all available information for each well, and especially the chemical data for each well, will not be released until later this year. Consequently, although the portion of the compilation which has already been released is an important contribution, it provides insufficient detail for an in-depth analysis of water quality or of other ground water characteristics. These data would be of great help in a comparison of aquifers and in the analyses of regional trends in water quality.

Another limitation in our investigation was that private mining and petroleum companies from the area were occasionally hesitant to release data and information concerning their programs because such data and information are considered proprietary. Consequently, most of our conclusions and recommendations are based on data and information which is available in public files, government reports, etc. As a result, our results occasionally may be considered out of date, considering the current status of industry knowledge concerning new techniques such as, for example, tertiary oil recovery techniques or solution mining techniques. However, we feel that adequate data

and information exist for the development of conclusions and recommendations which are of significance and will provide an adequate basis for the development of regulations with respect to these activities in the future.

SECTION IV

GROUND WATER CONTAMINATION DUE TO URANIUM EXPLORATION AND SOLUTION MINING

IV. GROUND WATER CONTAMINATION DUE TO URANIUM EXPLORATION AND SOLUTION MININC

In this portion of our report we will examine the characteristic geology of uranium deposits, its potential in southeastern Montana, exploration techniques, alternative mining methods including solution mining and regulation of the solution mining industry.

Two major mining methods, open pit and underground, have been used in the past to mine uranium. A new method, solution mining, has been developed and shows promise as an economical method of mining uranium. Because solution mining is relatively new and generally untested, the impacts of this method on the environment are not totally documented. The primary objectives of this report are to explain solution mining, evaluate the advantaged and disadvantages of this method, review regulations applicable to solution mining in Montana, and provide recommendations for regulating this method of mining.

GEOLOGY OF DEPOSITS

In the western portion of the United States there are basically three different types of uranium ore bodies encountered: tabular, vein and roll-front. Of these, only roll-front deposits are of significant importance in southeastern Montana; however, we will briefly discuss all three methods.

Typically in the western part of Colorado and Utah, uranium deposits are located in sandstone lenses and shales in a tabular fashion, and typically called tabular ore bodies. In the Precambrian rocks of the Front Range of the Rocky Mountains of Colorado and in areas of the northern Rockies in Montana, uranium occurs in veins which are fractures filled with uranium bearing minerals such as pitchblende. Vein deposits, generally, are small localized deposits commonly of moderately high grade.

In the Powder River Basin of Wyoming and in southwest Texas, uranium typically occurs in what is known to geologists as a roll-front. Roll-front deposits and uranium in lignite are the most probable types to occur in the region of southeast Montana and are, therefore, of most interest. Roll-front deposits have been extensively developed in the Powder River Basin in Wyoming. This development has led to extensive study of the

deposits, and a model has been developed to explain the origin and deposition of the uranium.

Generally it is believed that the uranium was originally deposited in beds of volcanic ash. Much later as a result of hydrolysis, the uranium, perhaps with vanadium, selenium, and molybdenum from the volcanic ash, was transmitted by an oxidizing slightly alkaline ground water through ancient buried stream channels of medium to coarse-grained alluvial arkosic sandstones. As the uranium-pregnant ground water moved through the sandstone alteration to the sandstone occurred. The feldsper grains altered to kaolinite clay; the iron minerals altered to hematite and limonite. Figure IV-1 shows the zones of rock alteration.

Although the mechanism causing the deposition of uranium is not totally understood, it is apparently related to a change in rock permeability, rock porosity, and the presence of reductants. At the point of deposition, which is a reducing-oxidizing interface, the uranium is precipitated from the solution as a fine coating on sandstone grains. In map view, the reducing-oxidizing interface, commonly called a roll-front, exists in a horseshoe shape with the tails pointing in the direction of the original source of uranium. In a cross section the roll-front appears horseshoe or C-shaped again with the tails pointing toward the original source. Quite commonly this roll-

front is not perfectly C-shaped and is complicated by local changes in lithology and different periods of uranium deposition. Generally, the roll-front thickens toward the front and the uranium is most highly concentrated in the frontal area. Figure IV-2 shows the zoning of the deposited ions.

It is generally thought that the uranium pregnant solutions can migrate for a considerable distance prior to final deposition. It is also thought that through changes in chemical quality of the ground water and changes in permeability, the uranium can be redissolved into solution and migrate to another deposition point. Consequently, the uranium may be deposited in a very complex ore body due to several episodes of migration.

The most common uranium minerals found in a roll-front deposit are uraninite, UO_2 to U_3O_8, and coffinite. Near surface weathering alters these minerals to tyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot nH_2O$, carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ and uranophane, a calcium uranium silicate.

EXPLORATION TECHNIQUES

Although each company searching for uranium has its own procedures and methods of exploration, these exploration procedures can be generalized into: 1) regional evaluation, 2) local target evaluation, and 3) target development.

Regional Evaluation

The regional target evaluation procedures utilizes many techniques, such as review of existing reports of occurrences of uranium in an area, rumors, radiometric aerial surveys of large areas, stream sediment sampling to locate anomalous concentrations of uranium, geologic mapping and modeling and reconnaissance drilling. Occasionally, prospecting is done by small operators who drill a small number of test holes in hopes of randomly locating uranium mineralization.

Local Target Evaluation

Generally, the well organized staff of explorationists will investigate a rather large area such as the Powder River Basin and eliminate those areas that geologically are not favorable. They then utilize past mining industry exploration data to eliminate additional areas until fairly small local targets are selected. During the evaluation of these local targets, widely spaced drilling of test holes is often conducted.

The test holes vary in grid distances typically on the order of one mile part. These holes are commonly drilled through the entire stratagraphic section that is thought to be uranium bearing. Normally, a 4 3/4 inch diameter hole is drilled with rotary drilling equipment. Normal depths range from approximately 500 to 1000 feet, although drilling has been exceeded by 2,000 feet.

Generally, the boreholes are geophysically logged to measure gross gamma radiation, formation resistivity, and spontaneous potential developed between contacts separating geologic formations. This information coupled with collected samples of drill cuttings is used to correlate between drill holes and develop an interpretation of the subsurface geology. Areas of anomalous characteristics are further evaluated with more closely spaced drill holes to core the zone of interest to recover undisturbed samples of the formation for closer geologic and chemical laboratory analysis.

Target Development

If uranium is found to exist in concentrations approaching economically mineable grades extensive development drilling is undertaken on closely spaced holes to define the roll-front, ore thickness and location. These holes may be spaced at the surface on 20 foot centers. Figure IV-3 shows hypothetical drilling

program. In the past closely spaced drilling has been required to evaluate the ore grade, total reserves, and depth of burial. This information, coupled with data on site accessability, market conditions, topographic conditions and ground water conditions, is utilized to develop an economic plan for mining the deposit. Once a mining method is selected and mining begins continued drilling occurs ahead of the mining to verify and project ore trends.

DRILLING AND GROUND WATER CONTAMINATION

Drilling Techniques

In most cases the exploration drilling is conducted at fast rates on mobile drilling rigs that are capable of up to 40,000 to 50,000 feet of drilling per rig per month. Drilling is normally done by one of two common methods. The most common is mud rotary method, which uses a bentonite-water fluid (mud) circulating downward through the drill pipe and upward through the annulus between the pipe and the drill hole. The fluid provides cooling to the drill bit and a method of floating the cuttings out of the drill hole. The second method utilizes compressed air to produce the same results.

The advantage of a bentonite mud system is that it allows drilling to proceed in areas of water-saturated or unconsolidated rocks. The drilling mud tends to infiltrate into water bearing horizons, clogging the pore

space in the vicinity of the drill hole and reducing the amount of fluid lost to the permeable formation. The mud weight establishes an equilibrium between formation and borehole pressures to prevent the drill hole from caving during the drilling operation. The advantages of drilling with compressed air are the speed at which drilling can proceed and higher efficiency of cuttings removal, both of which reduce cost.

Potential Ground Water Contamination

Exploration drilling can indirectly cause ground water problems. Sterilization is generally not done nor are the holes commonly plugged to prevent interconnection between different water-saturated sandstone layers which may contain water of different qualities and different natural hydrostatic pressures. Generally, it is this interconnection rather than direct introduction of contaminants during drilling that is a significant problem. The interconnection between aquifers allows water to flow from the zone of high pressure to low pressure, thereby either draining the high pressure zone or reducing the pressure head and mixing waters of two different chemical qualities. If enough drill holes are completed in this manner in a given area the resulting pressure drop could dry up stock wells or produce detrimental changes in chemical water quality. Either of these problems adversely

affects ranchers or others living in the vicinity of exploration programs.

Attempted Remedial Measures

The mining industry commonly considers it uneconomical to prevent this cross contamination by installing casing and grout to separate aquifers. In Montana, Wyoming and other states it is common to fill the drill hole with heavy bentonite drilling fluid to prevent the cross contamination; drillers also place a cement plug at the ground surface to prevent contaminants and pollutants from entering the borehole following drilling completion. The success of this method has not been comprehensively studied, but it has become standard practice and is assumed to be satisfactory. This method is fairly inexpensive and exploration companies have been willing to expend the extra money to satisfy state requirements in this way.

Our experience has shown that in numerous areas of Colorado and Wyoming where plugging with bentonite and a cement cap was reportedly done, it has not been done. Apparently, in some areas where bentonite sealing has been done the bentonite fluid was not prepared properly.

In some areas, typically in Montana and Wyoming where the population density is so low, the interconnection of aquifers has not been considered a problem. In some cases interconnection has not been detected because the use of the aquifers as water supplies has been slight. We assume that in some cases the interconnected waters are similar in chemical quality or pressure so that the interconnection has not become a problem under natural pressures. In Texas and in eastern Colorado where population density is much higher, very obvious changes in water quality and formation pressures have been reported.
Figure IV-4 is a generalized map of the Yellowstone-Tongue APO showing the areas of recent uranium exploration activity. Table IV-1 is a summary of exploration permits in the Yellowstone-Tongue APO.

MINING TECHNIQUES

Uranium has been historically mined by one or two major techniques. These are open pit surface mining, and underground mining.

Open Pit Mining

Open pit mining is commonly considered the more economical when comparing the cost of mining to the return upon sale of the product. Open pit mining is commonly done in areas where the uranium ore is near the surface. This method allows low ore grades to be economically mined. The amount of recoverable ore is greater using open pit mining since no support blocks have to be left as must be done in underground mining.

The limitations of open pit mining are the thickness of the overburden between the surface and uranium ore, the difficulty of mining the overburden, the amount of water-saturated material to be dewatered to reach the ore, and the surface restoration requirements of the state and federal authorities.

Underground Mining

Underground mining usually entails shafts, tunnels, and adits to reach the uranium ore body it is usually used to selectively mine only the highest grade ore due to the high cost of these underground workings. This method is utilized where high grade uranium deposits are at depths too great for open pit mining.

Sometimes underground mining is done because regulations limit surface mining. Problems associated with the underground method involve the following: high cost per ton of ore mined, ventilating underground workings to reduce hazard of radon and other gases, dewatering shafts and tunnels, inhalation of particulates by personnel, continual exposure of personnel to high noise level, and the possibility of surface settlement due to underground workings.

Solution Mining

During the last decade solution mining has been developed to mine uranium. This method utilizes chemicals injected into the ore zone to leach uranium and return it into solution. The uranium pregnant solution is then pumped from the ore body to the surface where the uranium component is concentrated. The advantages of this method are that it minimizes surface damage, is not depth dependent, allows low grade deposits to be mined, does not require as high an investment in capital and equipment, and does not have the ventilation, radon or noise problems.

The problems associated with solution mining include the possibility of the chemical solutions escaping from the control of the solution mining operator, the possibility that unanticipated chemical reactions may

occur and uncontrolled leakage of chemicals from one aquifer to another. Improper well completion, and abandoned or faulty well casing in the solution mining field may cause pollution of other aquifers.

SOLUTION MINING METHOD

Solution mining of uranium is the in situ leaching of uranium and transporting it to the surface where it is separated from the leach solution and concentrated. The process description is shown diagramatically on Figure IV-5. For solution mining to be successful the ore zones must be porous and permeable enough to serve as conduits for the migration of the uranium pregnant solutions. The porosity and permeability can not be so high as to cause too rapid migration, nor can the natural ground water velocity be so high as to cause escape of the injection fluids beyond the well field. Generally neither extreme condition exists.

Uranium Leaching Process

The leaching process includes drilling a series of wells into the ore body. Approximately half of these are injection wells and the other half are recovery wells. The wells can be arranged in different geometric patterns to derive the best recovery of solutions. Chemicals are injected into the injection wells either under pressure or by gravity feed to leach the uranium in place, allow it to become part of the ground water solution and migrate it to the recovery wells where it is pumped to the surface. The types of chemicals injected are dependent upon the preference of the mining company and the inplace geochemistry.

Westinghouse Corporation, currently considered the leader in the solution mining industry, utilizes a system injecting ammonium bicarbonate as a lixiviant and uses hydrogen peroxide as an oxidant. The concentrations used are generally weak. They are considered proprietary by the mining company, so their exact compositions have not been revealed.

The injection pressure and the pumping rates from the recovery wells are designed to establish equilibrium in the aquifer to allow the uranium solution and the injected chemicals to flow to the recovery wells with, theoretically, no escape of fluids. At the surface, the uranium-pregnant solution is run through an ionic exchange column to strip the uranium from the original injection solutions. The injection solutions are then reconstituted and reinjected into wells. This is shown on Figure IV-6. Once the uranium has been extracted it is precipitated as uranium slurry and then dried to form what is known as yellow-cake. The injection solutions are selected to minimize concentrations of other dissolvable ions to reduce the problem of disposing of these ions at the surface or the risk of ions escaping from the well field. A typical well field is shown on Figure IV-7.

Geochemistry and Hydrogeology

Prior to solution mining of an ore body most companies study the feasibility of solution mining and the geochemistry involved at the particular site. The hydrostatic pressures, the flow directions, velocities of migrating ground water, and porosity and permeability of each water saturated zone are all studied to determine the effects of injection and pumping on the hydrogeologic system. This information aids in selecting well location and geometry and design parameter of the wells. These studies are important to minimize the escape of ion solutions as well as to maximize the recovery of the uranium pregnant solution. The hydrogeologic information is determined from test holes completed as wells on which aquifer pumping tests are conducted and evaluated, from laboratory analysis of cores of the drill holes and from analysis of peizometric levels of all of the aquifers. Chemical analyses of the natural ground water and of the constituents of the rocks are evaluated to determine the concentrations of chemicals needed to dissolve the uranium mineral coating on the sand grains and also to evaluate the other chemical reactions which might result from the injection of the chemicals.

The ions expected to be mobilized utilizing the ammonium bicarbonate and hydrogen peroxide method in

order of decreasing concentration are calcium V_2O_5, SiO_2, aluminum, magnesium and molybdenum.

Uranium is only one element of a number of elements in the radioactive decay series. It is, therfore, possible that following complete removal of the uranium from the ore body a number of radioactive materials may remain. These are largely radon, radium 226, decay products of uranium, thorium, and potassium. However, the general belief is that solution mining does not serve to further concentrate these ions and generally does not dissolve a great number of the radioactive materials. They are generally left in place. It is possible, however, that some of these daughter products are dissolved and either carried to the surface or left in the aquifer as a result of the solution mining process.

Restoration of Aquifer

After completion of the solution mining, the aquifer is restored to a condition somewhat equivalent to that before mining by injecting chemical solutions into the aquifer to reverse or balance the chemical reactions caused by the initial injection. During the restoration stage chemical solutions are injected and recovered in a continuous cycle to replace the ions extracted or precipitate those ions mobilized. The chemical solutions utilized during restoration may result in mobilization of other ions, which may or may not remain

in solution upon completion of the restoration process. The nature of the chemicals injected and the amount of restoration necessary generally is dependent upon the original water quality.

Frequently the ground water quality associated with uranium deposits is such that it is not potable by humans or livestock prior to mining. Therefore, it is generally thought unnecessary to attempt to make this water potable following solution mining.

If, however, the uranium deposit occurs in an aquifer of potable water that is or may be utilized as a water supply the degree of restoration is generally greater in an attempt to return the water quality to a potable nature. Following restoration, wells are usually cement-grouted bottom to surface to prevent contamination or migration of fluids between aquifers.

Abandonment and Monitoring

During the initial well installation, monitor wells would be installed around the perimeter of the facility to monitor the possible escape of the fluids. Generally, it is wise to complete monitoring wells in both the overlying and underlying aquifers in the area to detect any cross contamination of aquifers.

A problem which may be of concern is contamination of aquifers due to leakage through old abandoned drill holes. Quite commonly an area selected for mining has

been extensively drilled by both the current operator and previous explorers. Commonly the holes have been abandoned to seal themselves or they have been filled with bentonite drilling fluid to serve as a barrier to prevent migration of ground water from a zone of high pressure to one of low pressure. It has been our experience that these holes do not effectively seal and while leakage may not be evident at the surface cross contamination of leaching fluid may occur during or after solution mining. It is diffucult during the solution mining to know whether leakage is occurring if there is no surface evidence nor monitoring wells to detect changes in hydrostatic pressure or changes in chemical content of water.

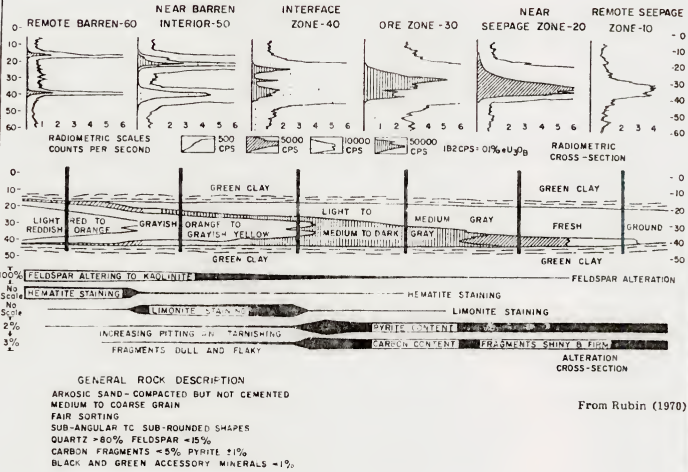
Another cause of cross contamination of aquifers is natural leakage through the confining aquicludes (strata of low permeability). In most circumstances the barriers are sufficiently impermeable to restrict any cross contamination but they may not be in other cases. It is important that the integrity of the confining shales between aquifers be examined to determine the potential of cross contamination.

Feasibility of Solution Mining

As in all uranium mining methods there is a certain amount of risk due to the radioactive nature of the product. Fortunately the concentrated uranium

that is at the mine site as yellow-cake is not generally highly radioactive and can be safely handled. There are numerous regulations to control disposal and transportation of this material; these are followed by companies in the industry. Enforcement of reasonable regulations, however, is necessary. Solution mining operators must also consider the risk hazard due to surface spills, flooding, or leakage of the chemicals at the concentrating facility. These chemicals can be carried in precipitation, runoff, or absorbed into the soil where they might pose a hazard in the future. However, with care, these spills and leaks can be prevented or at least minimized.

In summary, solution mining is technically feasible. It can be done with minimal risk to ground water supplies, but prior careful study of the local hydrogeology must be conducted, and the leaching program must be designed to prevent loss of solutions. It is ultimately most important that the company conducting the leaching operation understands the technique they are using, the potential hazards, the need for adequate monitoring before, during, and after the solution mining to ensure that the mining can be done safely without pollution.

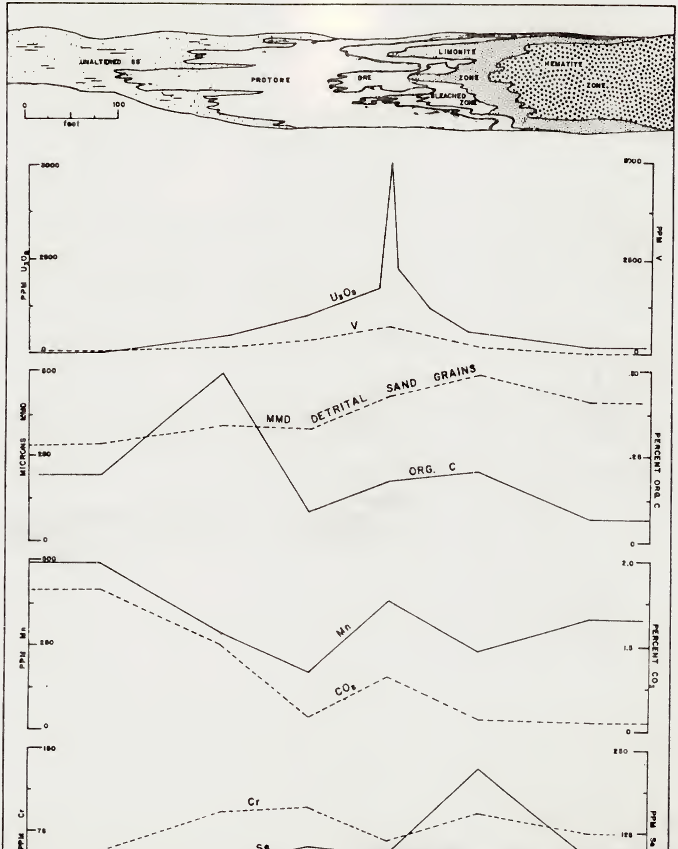


From Boberg 1975 and Rubin 1970

WILLARD OWENS ASSOCIATES INC

PROJECT NO. 5023

ROLL-FRONT URANIUM DEPOSIT WITH ZONES OF ROCK ALTERATION



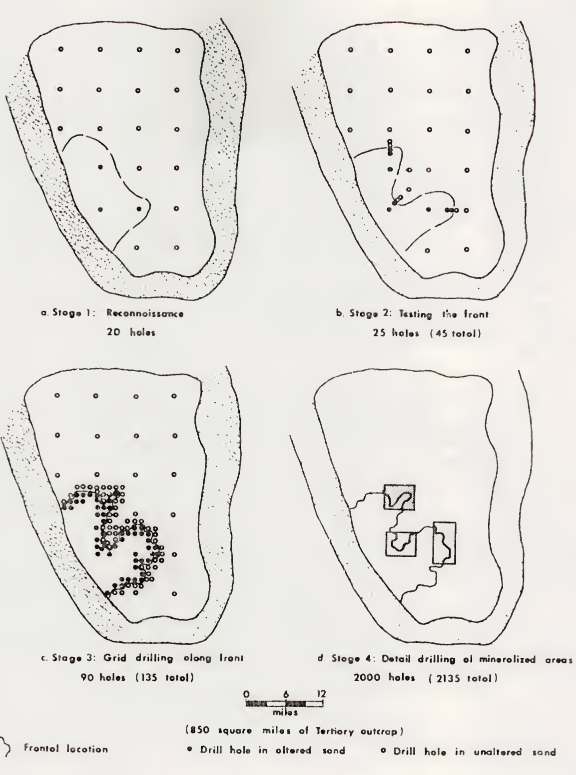
Roll-Front Deposit with Zones of Ion Precipitation

WILLARD OWENS ASSOCIATES INC

Vertical section with analytical data from an unoxidized Powder River Basin ore body.

UNION PACIFIC RR CO., NATURAL RESOURCES DIVISION CORE HOLE DATA

From Davis 1979 PROJECT NO. 6023 FIGURE IV-2



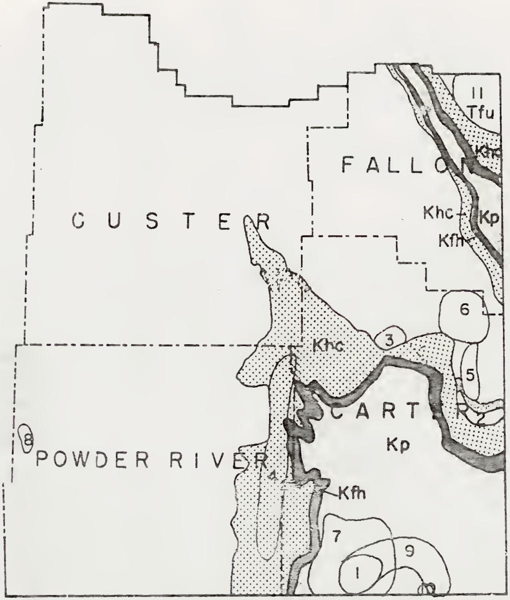
From Boberg 1975

WILLARD OWENS ASSOCIATES INC

PROJECT NO. 6023

HYPOTHETICAL DRILLING SEQUENCE FOR URANIUM

FIGURE IV-3



EXPLANATION

Tfu — FORT UNION FORMATION- Little uranium exploration activity

area of uranium bearing lignite coal

Khc — HELL CREEK FORMATION Some uranium exploration activity Much drilling to reach underlying Kfh

Kfh — FOX HILLS FORMATION- Significant uranium exploration activity

Kp — CRETACEOUS AGE FORMATIONS UNDIVIDED- Area of greatest uranium exploration

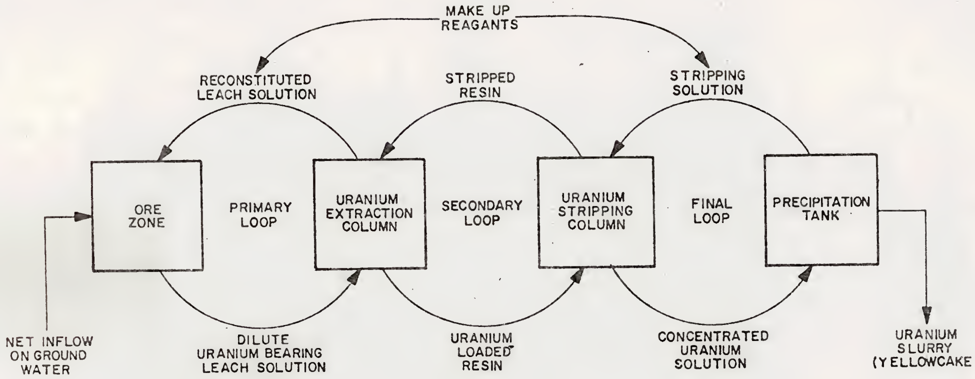
9 — Areas of exploration permits Numbers refer to TABLE I

GENERALIZED GEOLOGIC MAP WITH AREAS OF URANIUM EXPLORATION

WILLARD OWENS ASSOCIATES INC

PROJECT NO. 6023

FIGURE IV-4



WILLARD OWENS
ASSOCIATES
INC

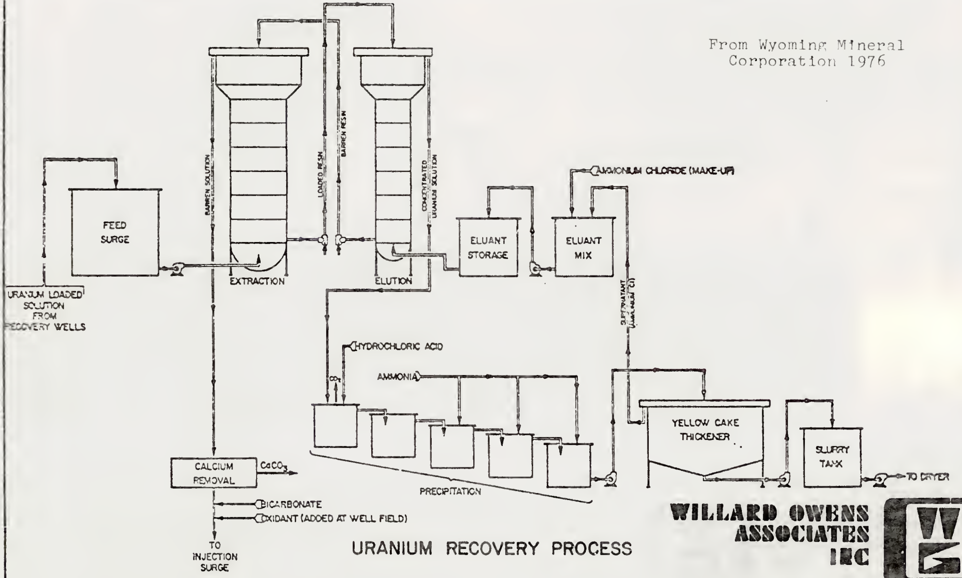
PROJECT NO. 6023

From Wyoming Mineral
Corporation 1976

SOLUTION MINING PROCESS

FIGURE IV-5

From Wyoming Mineral
Corporation 1976

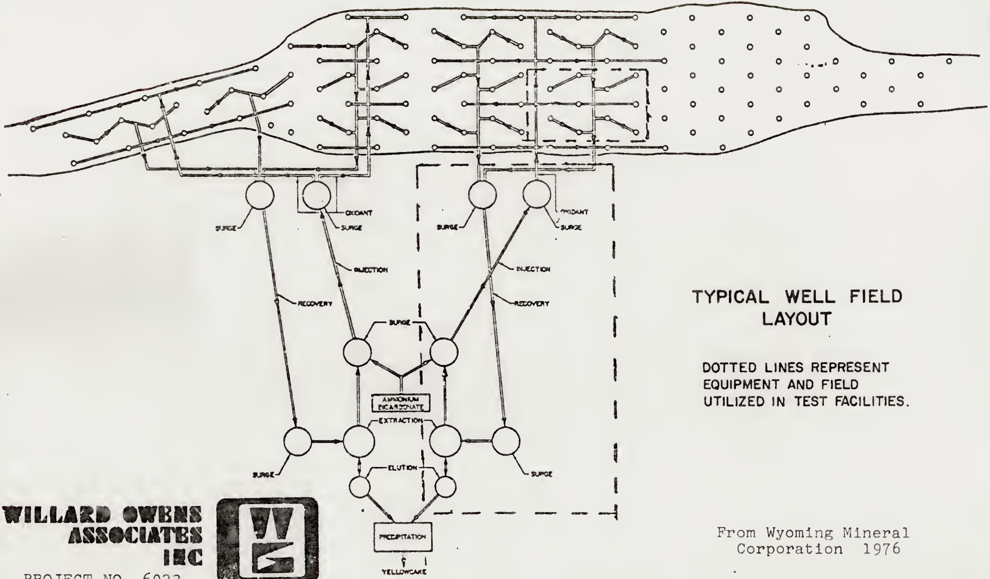


URANIUM RECOVERY PROCESS

WILLARD OWENS ASSOCIATES INC

PROJECT NO. 6023

FIGURE IV-6



TYPICAL WELL FIELD LAYOUT

DOTTED LINES REPRESENT EQUIPMENT AND FIELD UTILIZED IN TEST FACILITIES.

From Wyoming Mineral Corporation 1976

WILLARD OWENS ASSOCIATES INC

PROJECT NO. 6023

FIGURE IV-7

TABLE IV-1

URANIUM EXPLORATION PERMITS

IN THE YTAPO STUDY AREA

Company	Application Number	Permit Number*	County	Status	Approximate Holes Drilled
Kerr-McGee	1	5	Carter	Expired	-
Kerr-McGee	116	75107	Carter	Renewal of 5	330
Mobil Oil	4	3	Carter	now 75083R	200
Mobil Oil	9	7	Fallon	Expired	36
Mobil Oil	82	77	Powder River	Renewed	20
Felmont Oil	11	15	Carter	now 75134	125-175
Felmont Oil	108	75134	Carter	?	70
Teton Exploration	16	16	Fallon	Inactive	45
American Nuclear	17	13	Carter	Inactive	45
American Nuclear	54	49	Carter	Expired	-
Montana Nuclear	27		Carter	?	-
Exxon	76	72	Carter	Renewed	450
N.R.G.	86	78	Powder River	Expired	25
Pioneer Nuclear, Inc.	136	75128	Carter	?	12

* Single digits indicate 1972 (first year of permit regulations), in multiple digit numbers, first two digits indicate year e.g. 75128 means permit 128 in year 1975.

TABLE IV-1
con't.

The following are numbered to correspond with the numbered areas shown on Figure IV-4.

(1) Kerr-McGee 00005

Original permit was for 80 holes approximately 1200 feet deep, less than or equal to 5 inches in diameter. Drill sites 50 ft. square, or less than 1/10 of an acre. The holes pierce the Lakota (?) formation.

In April, 1974, in reply to State Lands, Kerr-McGee said they had no plans for development.

Kerr-McGee filed for lode claim on 8S 57E 23 B&C. 103 holes drilled in 9S 57E 23.

USGS was concerned that such a large exploratory program would damage the Muddy Sands producing horizon. Kerr-McGee stated that Muddy Sands formation near Alzada was too silty to be a good reservoir rock for oil.

We have a list of where all the 300 holes were drilled should you need them. This exploratory program is the largest in the area except for Exxon, and was all within the Alzada area of Carter County. Exploration has continued into this past summer.

(2) Mobil Oil 00003 "Fox Hills Project"

Originally requested 38 holes 200-1200 feet deep, less than or equal to 5 inches in diameter, near Camp Crook, South Dakota, and Capitol Rock Mt. in Carter County. The holes were to be plugged to 50 feet below the Fox Hills formation. Area of interest is 3S 62E 7,8,9,15,16,17,18,20 and 22.

State requested that prospecting stop in 3S 62E 2-22 because of danger to Capitol Rock, which is deemed a unique geological formation subject to protection.

State Fish & Game sought to exclude Long Pines area of Custer National Forest from exploration because of wildlife habitat.

380 acres around Capitol Rock were withdrawn form "mineral entry" by the Forest Service.

Ammendment to permit were requested for more holes in 2S 61E 36 (3holes), 3S 61E 1, 3S 62E 4,5,6,9,10,29,34, and 4S 62E 3,9,10.

Mobil also planned a string of holes 1.25 miles long 30 feet apart in 3S 62E 5,8, and 9. Forest Service became concerned over possible aquifer pollutions and requested state to require at least 100 feet concrete plug at both bottom and top of Fox Hills aquifer. State disagreed over necessity of 100 feet plugs and settled for 50 feet instead.

Mobil is looking for "roll front" type of uranium occurrence located in the Fox Hills sandstone

Mobil has staked claims to 36,620 acres of the 69,996 acres in the Long Pines area.

(3) Mobil Oil 00007 Fallon County "Ekalaka Project"

36 Holes. Very limited project in Ekalaka Hills area.

(4) Mobil Oil 00077 Powder River County

Holes in the Hell Creek outcrop area, again, a much more limited program than in the Long Pines area.

Holes in 1S 54E 9,32,35, 2S 54E 29, 3S 54E 15, 4S 54E 6,32,27, 5S 54E 15,30, 7S 54E 12, and 8S 54E 23.

(5) Felmont Oil Corporation 00015 Carter County "Grassy Butte Prospect"

125 holes 100-500 feet deep on ½ to 1 miles centers. Holes will "collar" Lebo shale member of Fort Union formation and bottom in the Hell Creek. Could drill as many as 173 holes. All in 1S 61E and 2S 61E. Felmont staked mining claims on 1N 61E 14,15,22,23,25, and 26.

(6) Felmont Oil Corporation 75134 Carter County "Box Elder Creek Prospect"

70 holes in first phase. Felmont has leases in 1N 61E and would also drill holes in 1N 60E, 2N 61E, and 2N 62E.

(7) American Nuclear 00013 & 00049 Carter County

45 holes initially to locate uranium bearing sandstone in the Inyan Kara geologic sequence at depths greater than 1200 feet.

Holes on " Claims" in Alzada area. 7,8,& 9S, 56, 57, and 59E. Some holes will be under "TEX" claims.

Montana Nuclear No Permit Granted Because of Bonding Problem.

8S 58E 01 (3holes) 8S 59E 04(4) 5(4) and 6(4) 7S 59E 34(5) 35(7) 26(1) 25(3).

(8) N.R.G. 00078 Powder River County

12 miles southeast of Ashland 25 holes 300 feet deep will be drilled along Otter Creek. 4S 45E 22, and 27.

(9) Exxon 00072 Carter County

213 holes initially on mining property leases and options from Montana Nuclear. 9S 57E, 8S 57E, 8S 58E, 8S 59E, 8S 60E, 9S 60E. 86 additional holes were included. Holes were to be drilled to 1800 feet deep. 151 more holes were added. Because of the depth of mineralization (1800-2000 ft.), Exxon will consider using either conventional deep mining or in place leaching. The earliest possible development date is in the mid to late 80's.

(10) Pioneer Nuclear, Inc. 75128 Carter County

2-5 holes 800 feet deep in 9S 59E 32 & 33, an additional 7 holes were ammended.

(11) Teton Exploration 00016 Fallon County "Ollie-Carlysle Project"

30 seismic shot holes at original depth of 200 feet. 10N 61E 8, and 9.

SECTION V

GROUND WATER CONTAMINATION DUE TO PETROLEUM EXPLORATION AND DEVELOPMENT

V. GROUND WATER CONTAMINATION DUE TO PETROLEUM EXPLORATION AND DEVELOPMENT

GEOLOGY OF DEPOSITS

The oil fields in the project area occur as clusters in three separate areas. These areas are (Figure I-2):

1) an area in the very northwestern portion of Rosebud county,
2) an area in southeastern Powder River county, and
3) an area trending northwest to southeast through Fallon county.

Production from Fallon county is coincident with a zone parallel to the axis of the Cedar Creek Anticline. The oil is concentrated along the crest of the anticline where it has been structurally trapped. The field is 57 miles long in Montana alone. Production is from porous carbonate rocks of Ordovician to Mississippian age. The oil fields occur at depths from 7,300 to 9,600 feet, three to four times the depth of gas-producing sand zones directly above the oil.

In contrast to the structural conditions which trap the oil in the Cedar Creek anticline, the oil in Powder River county was trapped stratigraphically. The Bell Creek field, which was the first giant oil field discovered in the Powder River Basin in over 50 years, illustrates the relationships involved. The Bell Creek field is located in very southeastern Powder River county and is

elongate in a northeast-southwest direction parallel with the strike of the rocks, which dip northwestward towards the axis of the Powder River Basin (Figure V-1). The oil is in the Muddy Sandstone of early Cretaceous age, which is unusually thick and permeable here as compared to areas further south of Wyoming. Previous to the discovery of the Bell Creek field, only one Muddy Sandstone oil field, Ranch Creek, had been developed before 1967 in Montana. Production from the Ranch Creek field was disappointing. However, a wildcat that was drilled five miles northeast of Ranch Creek along the structural and stratigraphic strike resulted in the Bell Creek discovery.

Petrographic analysis has confirmed that the main reservoir at Bell Creek is a barrier-bar deposit (Figure V-2). As such, the dominently fine-grained, permeable sand reservoir with an average thickness of twenty feet, is parctically isolated by shales from other sands (Figures V-3 & 4). Porosity reaches 33%, and permeabilities are as great as 13,500 milli-darcies. Drilling which followed Bell Creek resulted in important discoveries at eight other wildcat locations in the area.

The oil in Rosebud county in the northwestern part of the project area has different geological controls from that of the other two areas. It occurs in the Tyler formation, which contains the major reservoirs of central Montana and consists of channel deposits filling valleys due to stream incision into the underlying

Heath shale. The major fields in the area have been located where these elongate channel deposits coincide with anticlinal axes. Consequently, the oil was concentrated in combination structural-stratigraphic traps. Oil in both Rosebud and Powder River counties occurs at depths from 4,500 to 5,000 feet.

PETROLEUM EXPLORATION AND GROUND WATER CONTAMINATION

The methods of exploration for oil first used involved the search for "red flags", which were characteristically seeps of oil, tar, or other indicators at shallow depth. Following the location of these "red flags", it was a simple matter to drill in a down-dip direction to search for the source of the hydrocarbon. However, oil explorationists rapidly recognized that oil is frequently concentrated along the structural highs of domes or anticlines. Such structures then became major targets of exploration. Through time, it was learned that other preferred zones of oil concentration existed. For example, stratigraphic traps (pinchouts of permeable reservoirs in updip directions), fault truncations of reservoir rocks, salt domes, and porous limestone reservoirs were recognized as important targets. Such targets were generally located using traditional geologic mapping methods.

However, in order to determine structural and stratigraphic conditions more easily at depth, new methods were developed. Probably the most important of the geophysical methods is seismic, which is probably the most commonly used method today, but magnetic and gravity surveys are also important. Sedimentologic studies to predict sand-reservoir geometry and trend

are valuable ancillary tools. They augment the classical stratigraphic approaches to regional investigations.

Seismic techniques involve inducing energy into the earth's crust where it is reflected and refracted by the various subsurface geologic layers back to various pressure transducers where the travel times are recorded. This data is then interpreted to locate areas of geologic structure and stratigraphic variation which could serve as potential traps for petroleum. The most common technique of energy induction is to discharge explosives in drill holes, referred to as seismic shot holes.

The drilling and the explosive detonations can pollute the ground water by several means:

1. The inter-connection of aquifers of varying water quality;
2. The inter-connection of surface water run-off and ground water aquifers;
3. Chemicals introduced into the ground water as a result of the detonation of the explosive placed in the drill hole.

Some ranchers and farmers believe that seismic exploration will alter the subsurface by causing a change in permeability in the vicinity of wells. It is our opinion that there is little risk of change in permeability unless the explosion is very close to an existing well. In some cases the explosion may increase the permeability

due to the vibration removing the incrustation in the well casing. In other cases the explosion may cause a collapse of the well itself or sanding conditions. However, it is our general conclusion that the vibration from an explosion will not change the subsurface significantly or cause an area wide change in permeability.

In an area of resident complaints due to seismic activity affecting the quality of water or well yields, it is difficult to scientifically study these areas after the fact, because no baseline data is generally available to compare to results after seismic exploration. Residents and water well drillers commonly do not maintain records of water quality or accurate well yield. About the best that can be done in these situations is to evaluate the existing geology and type of seismic exploration activity to determine whether or not there is even the potential of change.

Old seismic holes that can be located can be sounded to determine their depth relative to existing wells. This information can be evaluated to determine the potential of inter-connection of ground water aquifers.

The pollution hazard due to the explosives utilized and changes to formation yield are difficult to determine. The best wat to study these effects is to conduct a baseline study prior to seismic investigation and then concurrently with and after the exploration program conduct a quality and quantity monitoring program.

Oil exploration wells are subject to the contamination problems previously discussed under modes of ground water contamination, and impose additional problems as they encounter brine-producing sands and formations under high pressure. Blow-outs are a constant threat of contamination to ground water aquifers. Breaks in casing or the sloughing off of material on the outside of the casing can result in a blow-out if pressurized hydrocarbons are encountered (Figure V-5).

Several strings of casing through the zone of water production can help protect ground water aquifers. Generally, a minimum of two casing strings are adequate. However, additional strings of casing might be needed if heaving shales or lost circulation are encountered or if drilling pressures are abnormally high. Adequate mud pressure must be maintained to prevent surficial blow-outs. Blow-outs in natural gas wells are especially hazardous if the gas contains sizable quantities of hydrogen sulphide.

Proper disposal of oil field brines has always been a problem. Disposal of brines through disposal wells and increased flooding by water can lead to movement of the brines up abandoned oil wells and penetration into the fresh water aquifers.

PETROLEUM DEVELOPMENT AND GROUND WATER CONTAMINATION

Three types of oil recovery are commonly distinguished - primary, secondary, and tertiary.

Primary recovery is that oil and gas produced by natural reservoir energy forces. The primary reservoir energy sources that cause oil to move toward a well are gravity, elastically-compressed reservoir rock, hydrostatic fluid pressure, compressed fluids, gas dissolved in oil, and free gas under pressure. Through these energy sources, a field may yield 20 to 30 percent of the oil in place, which is that fraction of the pore space filled with oil. Consequently, more than two-thirds of the oil in a field will not be recoverable through primary methods.

Secondary recovery is that oil or gas produced by an artificial restoration of energy after primary production ceases or is significantly reduced. Secondary recovery usually follows, but in some fields may be conducted concurrently with primary recovery methods. Waterflooding is the principal method of secondary recovery, but other ways of repressuring the reservoir are also included. Waterflooding is simply the injection of water into the reservoir through certain wells and withdrawal of the oil and gas from other wells. The oil or gas is pushed or driven towards the withdrawal wells by a bank of water. Through waterflooding, another one-third of the oil in place may be withdrawn from the reservoir.

After primary and secondary recovery processes are completed, as much as one-half, and possibly more, of the original oil in place will still be in the reservoir. This oil is partially removed through tertiary or enhanced recovery methods.

Tertiary oil recovery is of importance to the Yellowstone Tongue APO project because Gary Operating Company is initiating a pilot recovery test at the Bell Creek field, and enhanced recovery may be used elsewhere in the project area in the future. Gary plans to begin chemical injection through their injection wells within the next several months. Then it will require 9 to 12 months more to obtain the test results. They will employ a micellar-polymer test.

Three general types of enhanced recovery methods are available — miscible displacement, thermal recovery, and chemical flooding. These types are diagrammatically shown in Figure V-6.

The purpose of the miscible displacement recovery method is to inject a substance that is miscible with the reservoir oil. This substance overcomes those capilliary forces locking residual oil droplets in the interstices. It permits the movement of the injected fluid, which dislodges the oil and moves it to producing wells. Naptha, kerosene, and gasoline are miscible with typical reservoir oils, as are liquified petroleum gas products such as ethane, propane, and butane. Liquid hydrocarbons are miscible with oil immediately upon contact -

they have first contact miscibility. In contrast is multiple contact miscibility, in which high pressure gas or enriched gasses are injected, and successive encounters with the oil increases its mobility.

The uses of naptha, kerosene, and other miscible hydrocarbons are usually economically unpractical. However, propane is commonly economically feasible and thus is the method most often used in the miscible displacement, enhanced-recovery method.

The purpose of thermal recovery methods is to heat the reservoir and the oil within it to decrease the oil viscosity. Steam is often injected. By reducing the viscosity, a greater sweep efficiency is obtained. Basic methods of thermal recovery are hot-water flooding, cyclic steam injection, and steam drive. An additional thermal recovery technique is in situ combustion. In this method, the oil in the reservoir is ignited and the fire is sustained by air injection. The term "forward combustion" is often applied to this process. In forward combustion, the flame front is advancing in the same direction as the air movement is, from the injection well to the producing well. The increased temperature reduces the viscosity of the oil and it is driven towards a producing well.

The micellar-polymer solution flood processes are the most promising tertiary recovery techniques. They have good sweep efficiency plus they displace more of the contacted crude oil in the reservoir. Their primary

drawback is that they require large amounts of expensive chemicals.

A micellar solution can be described as a micro-emulsion. An emulsion is a mixture of mutually insoluble liquids in which one is dispersed in droplets throughout the other, for example, oil in water. In a micro-emulsion, the immersed particles are of microscopic size.

A micellar solution is a micro-emulsion of surfactant and water. A surfactant is a surface-active agent (or a soap-type substance) that has the ability to change the interfacial tension of the solution. Surfactants have molecules with one end attracted to oil and the other end attracted to the water. If the surfactant is mixed with water at a low concentration, it forms a solution. If the concentration is increased over some critical amount, the surfactant molecules cling together in clusters called micelles. If oil is mixed into this surfactant-water system, the micelles can dissolve it by forcing microscopic-size droplets into the center of the micelles. These are called swollen micelles. Thus, a micellar solution is formed of surfactants which essentially wash the oil from the interstices of the sedimentary formation. Alcohol is commonly added to the micellar solution as a co-surfactant. It helps adjust the viscosity and helps the micelles solubilize more oil or water and also reduce adsorption of the surfactant to the reservoir rock. Also, an electrolyte is commonly added to aid in the adjustment of the viscosity.

The micellar-polymer process which Gary Operating Company plans to employ in the Bell Creek field enhanced recovery operation is very simple. First, a period of pre-flushing will occur in which saline water is injected through the reservoir prior to the introduction of the micellar slug. Next, the micellar solution is injected into the reservoir. In the Bell Creek field, this solution will consist of sulphonated crude oil which will develop miscibility with the oil remaining in place. A polymer will be added for viscosity control. The polymer will be a polyacrylamide. The composition of the micellar slug will be a chain hydrocarbon with a SO_3H molecule on one end.

A significant factor involving the potential for ground water pollution in the micellar-polymer process is that of toxicity of the solutions. Table V-1 provides comparisons of materials used in micellar-polymer floods. The water quality criteria were developed by the EPA for the various uses of water in relation to these materials, along with estimated or test-derived concentrations of reservoir water after use of these materials. The table clearly shows that, after enhanced recovery operations, concentrations of these materials in reservoir water will always be excessive. Consequently, it is of the utmost importance that these materials do not migrate out of the reservoir.

An important element in this is that toxicity of all but a very few of the chemicals, and also their degradation products, are unknown, according to the Environmental

Protection Agency. Of course, toxic effects are concentration dependent. Because of filtration, dilution, and adsorption processes, chemicals released from an oil reservoir will decrease in concentration with distance travelled. Therefore, negligible concentrations may occur only a very short distance away. Furthermore, although much is known about the chemical compositions and effects on water quality of the chemicals themselves, their synergistic effects are not known in most instances. At the very least, surfactants, co-surfactants, and other chemicals used in enhanced recovery processes will impart undesirable tastes or odors to ground water and in some instances they will definitely be carcinogenic or toxic. In spite of these factors, we believe that the geologic environment, and especially the stratigraphic isolation of the Bell Creek field, is a factor which limits the possibility of ground water pollution in the surrounding aquifers from this source.

Micellar-polymer slugs were successfully used almost ten years ago. Forty-five to fifty percent of the post-waterflood oil has been recovered in tests employing micellar flooding.

Micellar solutions cost from $8.00 to $15.00 a barrel and, for this reason, are currently uneconomical for many fields. When the price of oil ultimately rises, micellar-polymer methods of enhanced oil recovery will undoubtedly increase.

A breakdown of active enhanced recovery projects in the United States is currently as follows:

Carbon Dioxide	9
Miscible Hydrocarbons	13
Micellar-Polymer	27
Steam	85
Combustion	21

These are in Pennsylvania, Illinois, Kansas, Oklahoma, Texas, Nebraska, Wyoming, Montana, and California. It should be emphasized that micellar-polymer projects are only in the testing phase currently and for full scale operations to be undertaken, much more testing will be necessary.

For methods of secondary and tertiary recovery, it is, of course, essential that the flow parameters and transmissability of the oil-and water-bearing strata be known. This understanding is sometimes achieved by the use of radioactive tracers that are injected into the strata. The movement of these tracers is monitored by a system of wells. The movement of water can thus be estimated for the practicality of flooding the oil field.

In itself, this method does not present a hazard as long as the radioactive material is confined to the oil-bearing strata and does not enter an aquifer. The potential for hazard can arise through possible casing leaks, spillage, and improper disposal of radioactive, tracer-bearing water as it emerges from the well.

It is thus important to know exactly what radioactive material is used, its half life and concentration, and exactly what effect is will have on potable water.

Water emerging from a well containing radioactive material should be recirculated back into the oil bearing zone to prevent contamination of surface water. Continuous monitoring should be maintained to determine if the radioactive water is somehow entering strata other than the oil bearing strata, whether by means of a casing break, fractures in the rock, solution cavities, or other means.

Another use of radioactive material in oil development is as a determination of formation permeability. Permeability in an uncased well can be determined by pumping down radioactive mud and then lowering a counter down the well. High radioactivity corresponds to areas with the highest penetration of the radioactive mud. The possibility of radioactive mud entering ground water aquifers exists and is a possible source of ground water pollution.

In some cases, oil field activity can bring about an increase of pre-existing sources of contamination of ground water. Such instances can include ground subsidence, additional fracturing, increasing potential for earth movement, and the creation of situations for oil seepages to occur.

As an oil field is pumped, subsidence can result when large amounts of fluid are withdrawn. This subsidence can in turn bring about fracturing, local flooding, and changes in the water table.

Subsurface blasting might be used to increase size of fractures and increase production.

As water is removed or added to the subsurface, a balance of pressures are affected that can result in earthquakes. An example of this is the earth movement experienced in Denver due to the deep well injection of wastes. Earthquake studies have taken place in northwest Colorado using this principal. Also as water and oil are removed, there is a chance of earth movement.

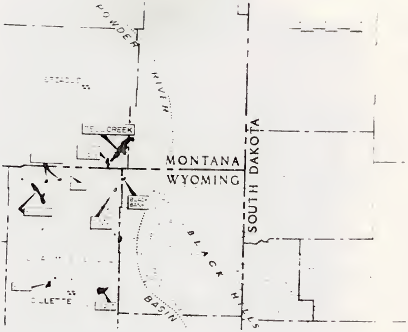


FIGURE V-1: Location of Bell Creek Field

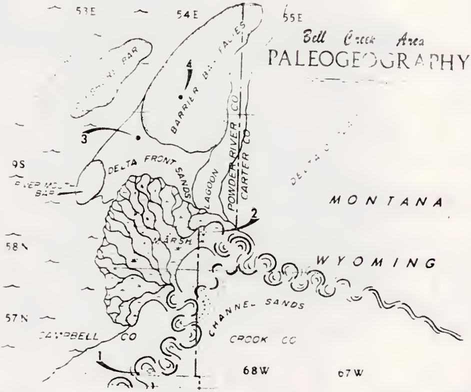


FIGURE V-2: Map Showing Barrier Bar is Principal Bell Creek Facies

WILLARD OWENS ASSOCIATES INC

From McGregor and Biggs, 1968.

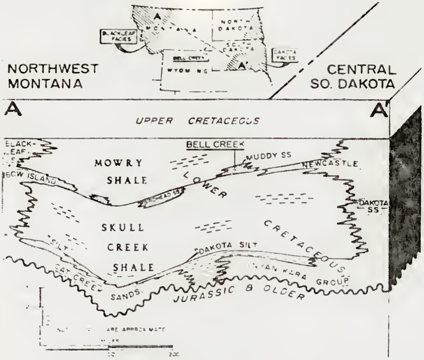


FIGURE V-3: Block Diagram Showing Isolation of Muddy Sand

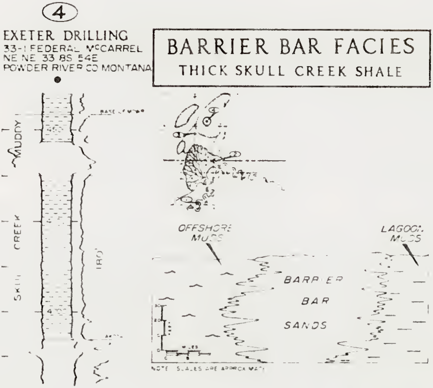


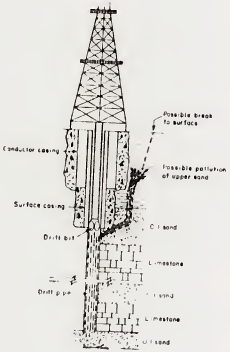
FIGURE V-4: Electric Log and Schematic of Barrier Bar Facies

WILLARD OWENS ASSOCIATES INC

From McGregor and Bi[illegible], 1966

FIGURES V-3 and V-4

WELL BLOWOUTS CAN PERMIT AQUIFER CONTAMINATION



From Campbell & Lehr, 1973.

SECTION VI

RECOMMENDATIONS

VI. RECOMMENDATIONS

While pollution to surface streams can be detected through stream monitoring and corrected at the source, pollution to underground aquifers cannot be detected so easily nor can pollution once introduced to the aquifers be easily removed. Even continued washing of aquifers, if it were economical or feasible, would be a long term, difficult process to conduct. Therefore, the best way to control pollution of aquifers is to prevent introduction of pollutants.

Our final recommendations are based on our evaluation of hydrogeologic conditions in the project area, our investigations of uranium and petroleum exploration and extraction programs, and our review of pertinent rules and regulations relating to these programs. These recommendations are basically divisible according to three topics - exploration activities, uranium solution mining, and enhanced oil recovery.

REGULATION OF EXPLORATION ACTIVITIES

Widely spaced drill holes resulting from petroleum and uranium exploration have definite potential for ground water contamination. Almost all this potential will be eliminated if abandoned holes are adequately plugged.

Oil Exploration

The Montana Oil and Gas Conservation Commission's Rules and Regulations governing oil well plugging are currently under revision, according to a verbal report from a representative of that body. The present Rules and Regulations do not specify that cement be used to plug abandoned oil wells. However, the Rules are enforced through the requirement of completion by the operator of a form that does specify cement plugs across porous zones and a required amount of cement (Appendix III). We recommend that the revised Rules and Regulations also require cement. We suggest that it be formally specified that cement plugs be adequately placed and monitored with regard to abandoned oil wells. We are aware of situations in other states where cement plugs were not adequately placed at aquifers, others where they reportedly moved downhole, and still others there, through hurrying and/or neglect, some important aquifers were not cemented as required.

fixed -

We also suggest that two additional procedures be followed. First, only cement that is insoluble in the respective formation water should be used. The cement

industry is quite advanced in this regard, and compositions of cement can be adjusted to be insoluble under almost all chemical ranges of formation waters. Where very corrosive conditions are encountered (e.g. high CO_2 waters), plastic pipe can be used and epoxy can be used to seal the well. Because a very wide range of conditions is possible, the type and density of cement or other plugging material should be specified for each environmental condition. Secondly, some type of long-term monitoring of plugs should be established. These requirements will help to achieve the goal that plugs will be effective indefinitely.

Uranium Exploration

In a manner analogous to that for oil companies, mining companies are required to obtain exploration permits from the Department of State Lands in order to explore in Montana. The department's rules and regulations require that mining companies submit with their applications information regarding number, depth, and location of holes planned, planned access roads, mthods of preventing pollution of ground water, and plans for reclamation. This information is evaluated and the permit is granted subject to the mining company's meeting the requirements. The department inspects the reclamation to insure compliance with the permit.

Having been involved in uranium exploration programs, we recognize the potential pollution hazard. However, we also recognize the cost burden of cement

grouting, additional permitting, etc., on the exploration programs. Our discussions with mining company personnel who have worked in Montana reveal that the smaller companies with limited exploration budgets have excluded Montana because of the state regulations. Personnel of larger companies, especially those that are divisions of major oil companies, told us during our interviews that while the permitting process slowed their program, they were prepared to continue and that they have sufficient capital to spend on exploration.

In discussions with personnel of mining companies who have explored in Montana and who have complied with state exploration permits, we learned that the method used to prevent ground water pollution was to fill the drill hole with heavy bentonite fluid and then place a cement plug at the surface.

The Department regulations allow the mining company to choose its method of pollution prevention; department personnel then review this proposal.

We feel that the Department's regulations are generally sufficient, but that more careful evaluation of proposed plugging methods may be necessary.

Appendix I is a copy of the plugging specifications used by Power Resources Corporation in their uranium exploration programs in Colorado, North Dakota, and South Dakota. The available evidence indicates that this hole-plugging procedure, which is modeled after and improves upon that approved by the New Mexico State Engineer

for use in uranium exploration in the San Juan Basin, should be more than satisfactory for the same purposes in Montana.

Therefore, we recommend that the New Mexico regulations serve as a basic regulatory model for those to be applied in Montana, but that Montana include additional detailed descriptions of procedures after those outlined by Power Resources. We propose that the following points be emphasized or amended:

1. Of course, the specification of Baroid products should not be made. Rather, the viscosity of the beneficiated bentonite mixture, its gel strength, and its filtrate volume should be emphasized. These should meet or exceed those provided by the Baroid mixture. However, only the viscosity should have to be measured for each hole and should be 20 seconds greater than that of the drilling mud. Thus, for mixtures developed by other companies, evidence will have to be produced that shows the required viscosity - gel strength - filtrate relationships before they will acceptable for use. If circulation is lost and a column of mud cannot be maintained, the hole shall be plugged with the cement slurry.

2. Flowing artesian wells should be plugged with a cement slurry of at least 15 pounds per gallon weight.

3. Reports on hole locations, depths, plugging procedure, etc. shall be required and a representative of the state shall be designated and an affidavit filed, as in New Mexico.

4. All holes shall be plugged from the bottom up, except as in #6, below.

5. Seismic holes shall be plugged by running non-metal drill pipe or hose into the hole to point between 15 and 20 feet above the shot depth and then plugged as other holes.

6. Maximum depth of hole not required to be plugged from bottom up is 20 feet.

7. All holes shall be plugged with cement from the ground surface to a depth of 8 feet. If in plowed ground, the top of the plug can be 18" below the ground, with a metal marker to provide for location (See Power Resources procedures).

An optional method of ensuring proper hole plugging is a licensing program for exploration drilling contractors similar to that required of water well drilling contractors. This license would put the responsibility of proper plugging on the drilling contractor or other representative, but someone who is in the best position to see that the plugging is done correctly. The license could require reports to be submitted on plugging and records to be kept by the contractor.

We believe that a careful balance is necessary to allow the exploration companies to seek the needed resource. However, they must recognize their obligation to protect the existing ground water resources. The degree to which this protection is guaranteed must be carefully weighed against the possible decrease in exploration activity and resulting adverse impact on local and state economy.

REGULATION OF SOLUTION MINING

Although solution mining of uranium has been conducted during the last several years, its practicality and effectiveness as a mining technique is still in the testing phase. Its relatively small cost compared to that of underground mining and open pit mining may result in it being a viable mining technique. Consequently it is wise to plan for the possibility that this technique may be used in southeastern Montana.

Expertise Requirements

Solution mining does not require particularly difficult techniques, and it can be safely conducted if the expertise is available to the operator. Solution mining requires a multi-disciplined approach with experts in hydrology, chemistry, water well construction and completion, ground water hydrology, and metallurgy. Presently there are very few groups other than major mining companies and oil companies that have such a diverse team available to successfully accomplish solution mining. Even the majors use consultants in some fields to complete the team. Consequently, to ensure that knowledgeable people are conducting solution mining regulations, you should include a system to evaluate the expertise of solution mining companies.

Hydrogeologic Studies

In order to protect the state's ground water resources, consideration should be given to establishing rules and

regulations within the existing framework of state agencies to require a permit for solution mining. This permit should be issued only after careful investigation.

Submitted with the permit application should be a description of the mining process and a plan for aquifer reclamation. The study should include a determination of the ground water gradient for each aquifer above the solution mining interval and for the shallowest aquifer underlying the interval. The study should also include an evaluation of porosity, permeability, storage coefficient or specific yield, direction of and rate of ground water migration, and the extent of aquifers in the area. The extent and hydrologic characteristics of confining strata need to be determined.

Included in the report on the results of the hydrogeologic study should be a discussion of the relationship between the aquifers and nearby surface water drainage systems as well as the relationship between the aquifers and nearby water supply wells. All water wells within a specified distance should be inventoried with water levels, pumping levels, well yields, well use, and well design all documented. All of the above information is necessary to evaluate the suitability of an area for solution mining.

Permit Procedures

Consideration should be given to requiring proof of competence in solution mining methods and techniques before an applicant is issued a pilot test permit and adequate

testing of a selected ore body should precede the issuance of a mining permit.

This pilot test would be utilized to determine the operator's capabilities to safely conduct solution mining under the specific geologic conditions. It would also allow him to evaluate his process to determine whether or not it would be suitable for the given geochemistry of the area. We also suggest that at the end of the solution mining test the operator be required to reclaim the area to applicable standards to show his capability to reclaim the aquifer. If after the pilot test the operator has shown sufficient competence to successfully complete the mining and reclamation, he then should be granted a permit for a given area and period of time.

Included with the application should be a sufficient amount of engineering data explaining the process to be used for either a pilot test facility or a mining facility. This information should explain the process, the equipment required and the well construction techniques to be utilized. Submitted with the engineering data should be a monitoring program to ensure that the solution mining is carried out safely. This monitoring program would necessarily include monitoring wells to determine whether fluids are escaping from the test site and whether pressure gradients in underlying and overlying aquifers are changing to indicate migration of fluids from one aquifer to another.

The monitoring program should also evaluate whether or not prior exploration drill holes are leaking not only at the surface but between aquifers. Sampling should be done in the production'recovery wells to determine whether or not the ions expected to be mobilized are in fact mobilized and those that were not expected to be mobilized are not being mobilized.

The operator should also be required to document emergency procedures that would outline the steps to be taken for a surface spill, leak, flooding or other problems of contamination to either personnel or equipment or the surrounding environment. Emergency procedures for controlling the escape of injection solution to underlying or overlying aquifers should be documented. As a condition or approval, the results of the monitoring program should be routinely submitted to the agency with a narrative analyzing the data.

The application should also include specific alternative methods of aquifer reclamation. The agency should realize that prior to mining, the operator may not specifically know which methods of reclamation would be most suitable. However, if the operator is required to conduct a pilot test with test reclamation, he will then know what methods will be necessary following full scale mining to adequately reclaim the aquifer. The operator should then submit a detailed plan to the agency for evaluation.

Bonding should be required to allow for reclamation of the area should the operator fail to do so for any reason. The amount of the bonding should be sufficient to include the cost of plugging all wells, removal of surface equipment, and reclamation of the affected ground water aquifers. Reclamation of the ground water aquifers would be the most expensive and the most difficult to define. Regulations controlling the solution mining operator should also provide for methods of revocation of permits, fines for infractions, as well as machinery for criminal punishment should the operator fail to comply with regulations.

ENHANCED OIL RECOVERY

Because a foreign chemical is injected into and extracted from a permeable formation in both processes, solution mining for uranium and enhanced oil recovery pose similar problems. However, a basic geologic difference between uranium solution mining and enhanced oil recovery is that oil is a fluid that is stratigraphically or structurally trapped and the permeable reservoir zone is commonly naturally isolated, while uranium roll fronts occur as zones of mineral concentration in commonly nonisolated aquifers that are characterized by through-flowing ground water.

Much higher injection pressures, reaching as high as 3,000 psi., will be subjected to wells involved in enhanced recovery processes. It is thus desirable that more rigorous procedures for monitoring the installation and maintenance of well casings be developed. Similarly, the plugging of wells should be monitored, including the installation of cement mixtures which will be compatible chemically with formation waters. Such compatible cement is not specified in the current regulations. In addition, we recommend that the requirements be initiated for the operators to neutralize contaminated aquifers which occur through faulty procedures that result in casing leaks and other modes of aquifer contamination. Where very corrosive conditions are encountered, for example; involving high carbonate waters, plastic pipe may have

to be specified and epoxy seals used. A very wide range of formation waters is possible and the type and density of cement or other plugging material should be specified for each environmental condition.

The most immediate potential problem related to enhanced oil recovery is that presented by the Bell Creek field micellar-polymer test.

The results of our investigation of the situation indicate that there is little danger of significant ground water contamination from Gary's recovery process as long as they adhere to the regulations and regulatory-agency processes involved. Gary Operating Company is familiar with injection-recovery techniques in the Bell Creek field through their waterflood activities, which they have been conducting for almost 10 years. The chemicals they will be injecting are very expensive, and because it is in their own best interest to achieve maximum recovery, they will undoubtedly take all necessary steps to minimize the loss of solutions while the recovery program is in progress. The Muddy Sand producing zone is deep (4,500 feet) and essentially isolated from important aquifers. Consequently, the greatest potential for ground water contamination will be associated with shallow-aquifer communication due to abandoned wells. It is the same problem of adequate hole-plugging procedures, and our recommendation is to require adequate cementing and monitoring of all wells associated with their process, as discussed in detail above.

MONTANA AGENCIES AND REGULATION

Results of our analysis of Montana water laws suggest that ground water pollution related to uranium and petroleum can be controlled within the framework of existing state agencies. It could probably be controlled without major changes in existing rules and regulations. However, we believe that in order to ensure an efficient evaluation of permit applications, it would probably be necessary to modify statutes as well as rules and regulations to specifically mention solution mining, enhanced oil recovery, and specific procedures to be followed. It also appears that several state agencies could exert control over these activities under present statutes. It will b necessary to define each agency's jurisdiction so that there is no interagency competition that would result in inefficient administration over solution mining.

It appears under the present system that control of these activities is distributed among the Department of Natural Resources, which controls well permits and well construction; the Department of State Lands, which controls mine siting, mine planning, and mine reclamation; and the Board and Department of Health and Environmental Sciences, which controls pollution to state waters. All of these agencies currently have permitting systems and rules and regulations controlling their area of responsibility.

After reviewing a document entitled "Montana Water Pollution Control Systems" prepared for the Montana State Department of Health and Environmental Sciences and a

document entitled "Proposed Guidelines for the Strip Mining, Reclamation Act", 1975, we conclude that both documents outline many of the necessary requirements we believe are necessary items previously mentioned herein to regulate the energy exploration industry. While the regulations from the Department of Health and Environmental Sciences do mention water quality standards, they do not require preparation of a plan for reclamation, nor set specific reclamation standards.

We feel that standards are necessary to ensure protection of the State's aquifers. These standards should be carefully thought out and should be based on a classification of the State's aquifers with regard to use and quality. Without a classification system based on existing quality, an operator may be required to restore the aquifer to a better condition than that prior to mining. It is entirely possible that in some areas, aquifer reclamation may not be necessary because its poor water quality precludes its use as a water supply in the future. Methods for determining the class of each ground water aquifer should be outlined in the rules and regulations; minimum standards of reclamation for each quality of water should be set by the regulations. Neither of the two reviewed documents discusses a monitoring program in detail. ALso, they do not indicate the types of material to be monitored or monitoring frequency. We believe that the regulations should set standards for frequency and method of monitoring.

Regulations ultimately established should be parallel for all operators involved in all drilling-based exploration and development methods. Because the Department of State Lands controls all other mining methods and reclamation it is logical for them to control solution mining. On the other hand it si the responsibility of the Department of Health and Environmental Sciences to control pollution to the State's waters; they, therefore, would be involved in enhanced recovery as well as solution mining. The Department of Natural Resources, which controls well drillers and well construction, would also necessarily be involved. Assuming that the existing framework continues, these agencies must determine their areas of responsibility to prevent unnecessary duplication of effort.

We expect that one of these three agencies would be selected as the lead agency with primary control over solution mining and enhanced oil recovery. The other two agencies could serve as advisors to the lead agency to analyze applications and set conditions for granting permits.

Because solution mining and enhanced oil recovery involve an interdisciplinary technology, the review must be an interdisciplinary evaluation. Expertise will be required in well construction, metallurgy, ground water chemistry, ground water hydrology, environmental sciences, and reclamation. Until these activities become sufficiently common to warrant the cost of full-time, qualified personnel

to provide adequate review, it might be wise to allow the agencies to retain outside consultants to aid in the evaluation of permit applications. This has been done successfully in other states.

SECTION VII

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

VII. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The principal purpose of our investigation was to determine the potential for ground water contamination in the project area due to the activities related to the extraction of and exploration for petroleum and uranium, and to develop recommendations for the prevention of future contamination. Meetings with the project staff concerning results obtained during the early stages of the study led to the agreement that our principal emphasis of investigation should focus on problems related to uranium exploration, uranium solution mining, and enhanced oil recovery. All these activities represent significant ground-water pollution potential in the study area.

Uranium exploration presents a potential problem because uranium occurs at relatively shallow depths and in those formations which are the principal aquifers in much of the area. Numerous drill holes are required to close in on the uranium roll-fronts, along which the ore typically occurs in pods normally only a few tens of feet wide. Consequently, the vast majority of exploration holes do not encounter ore and are abandoned. Plugging procedures for these holes are not currently standardized or sufficiently regulated. We recommend such a procedure and include specific details, with regulatory options. Basically, the recommendations involve plugging all exploration holes from the bottom up with, as a minimum,

beneficiated bentonite mud with specified, measured, documented, and inspected properties. We recommend similar procedures for seismic drill-hole plugging, and suggest the use of cement that is chemically compatible with the respective formation waters under some circumstances.

Uranium solution mining presents special problems because a chemical that will "leach" the uranium from the ore zone will be injected into an aquifer. Numerous wells only a few tens of feet apart will be required. Specific safeguards to ensure that injection and recovery wells do not leak and are adequately plugged when abandoned, that the injected chemicals are totally recovered or neutralized, and that the aquifer is restored and monitored, are suggested. These safeguards include satisfactory test procedures, and preliminary follow-up hydrologic analyses.

Enhanced oil recovery is similar to uranium solution mining in that foreign chemicals are injected into the subsurface and recovered. It is different because oil is typically "trapped" by various types of natural geologic barriers that prevent its migration. Thus, the oil-recovering chemicals are not normally injected into an aquifer with through-flowing ground water. The oil reservoirs in the area are thousands of feet deep. The greatest pollution potential from enhanced oil recovery comes from well casing leaks, spills that may reach aquifers, and inadequately plugged wells.

Like solution mining for uranium, the chemical technology of enhanced oil recovery pollution is insufficiently developed to evaluate all the possible ramifications of pollution to ground water; unlike solution mining for uranium, the injection-recovery processes are well-tested. The toxic, carcinogenic or other harmful effects of the chemicals and their synergistic products most recently developed and tested for enhanced oil recovery purposes are largely unknown. However, the high costs of many of these chemicals, now and for greatly increased oil prices, prohibit their widespread use and promote their control and conservation during use. Based on these and other factors, we recommend that rigorous plugging and monitoring specifications be developed for enhanced oil recovery, including the use of casing and cement plugs that are chemically compatible with formation waters, hydrogeologic system evaluations, monitoring, and aquifer restoration when necessary.

There is hardly anyone who does not recognize that energy-resource exploration and development are desirable and necessary activities, or that our aquifers need to be protected by those exploring for energy. Such protection will only occur through the development and enforcement of fair, reasonable, enforceable, and practicable regulations that protect the public interest. Such regulatory functions should be the responsibility of different governmental agencies, according to their different areas of expertise. However, because many of the problems involving ground

water pollution from energy-resource activities are similar or the same, there is logically some subjectivity as to the potentially most efficient method of governmental regulation.

Our review of the regulations governing the exploration and development of both uranium and oil indicate that they are currently not adequate for all possible contingencies and problems related to the future of solution mining and/or enhanced oil recovery in the project area. There is overlap among the agencies concerned with ground water pollution and no agency has sufficiently extensive control, without the possibility of usurping the functions of some other agency, to oversee these activities. In addition, some significant aspects of these energy-resource activities are not currently considered by any agency. Therefore, we recommend the following:

1. That one set of regulations be developed for those activities related to uranium exploration and development and another for those activities related to oil exploration and development.
2. That one agency be designated to adopt and enforce those regulations pertaining to uranium and another those pertaining to oil.
3. That the regulations adopted be reasonable, enforceable by the appropriate state agency involved, and still be practical for the development of the energy resource without unreasonable cost or requirements on the part of the company.

4. That specific procedures and requirements for the plugging of exploratory drill holes for uranium be adopted, commensurate with our recommendations set forth in this report.
5. That specific procedures and requirements for cementing and the type of cement of drill holes related to uranium solution mining and enhanced oil recovery be adopted according to the specifications as set forth in this report.
6. That sufficient time be allotted those companies exploring for uranium so compliance with any rules and regulations governing their exploration activity is possible.
7. That compliance with the adopted regulations be subject to that geologic information in existence and that new information will not have to be developed before exploration can begin.
8. That the permit procedure be sufficiently streamlined and efficient so it does not prevent exploration in Montana.
9. That the regulations be provincial where appropriate. As an example, exploration in artesian aquifers should not be automatically subject to the same hole-plugging requirements as exploration in unconfined aquifers.

With adequate planning and review to establish and ensure that geologic and hydrologic conditions are amenable to the extraction of these resources, disturbance of the ground water system and the risk of pollution can be minimized. However, regulations involving the entire spectrum of processes of exploration and development are currently inadequate and need to be updated to ensure the adequate protection of aquifers.

We believe that the state agencies can, through their statutory mandates, administer proper regulations concerning these energy-resource activities. However, there is apparent duplication of responsibility of regulatory authority which needs to be eliminated. We believe also that one agency should be designated as the lead agency to prepare rules and regulations to govern solution mining. The present regulatory process for oil exploration and development will basically suffice for the enhanced recovery techniques of the future, but additional safeguards involving the ground-water pollution potential of this method are recommended.

The public is generally not aware that ground water normally does not occur in underground streams nor does it flow at great velocities over large distances. We expect that this lack of knowledge will create general unfounded public concern that activities involving aquifers affected by uranium and oil exploration and development in the Yellowstone-Tongue project area will constitute

severe ground-water pollution hazards. This will not necessarily be the case. Most pollution to aquifers will generally be confined to a small area, will migrate at a slow rate, and will not likely be severe or uncontrollable. It remains only for the state of Montana to develop regulations affecting both uranium and petroleum activities that consider problems of reclamation, problems of adequately evaluating the hydrogeologic system, the operator's capabilities to conduct the operation successfully, safely, and without polluting, and the need for adequate monitoring. The regulations should protect the public's interest, while at the same time, provide a favorable climate for exploration and development of these energy resources.